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CASE STUDY OF FAILURE OF A R.C.C. COUNTERFORT RETAINING WALL

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ABSTRACT

It is a fact that the retaining wall failures have occurred in the distant past as also in recent times and will recur inevitably in future. The reasons of failure are ultimately the errors of judgment to which no humans including the greatest of engineers are immune. Free flow of information on failure incidents is greatly inhibited in most of the cases by the natural tendency to avoid publicizing our mistakes although all human are prone to them.

The present study through light on a failure of a recently constructed R.C.C. counter fort Retaining wall. The wall is located near Sangli city in Maharashtra state of India. The wall was constructed in 2003 and there was a heavy rainfall occurred in all over the Maharashtra state continuously in the year 2005 and 2006 subsequently in the catchments of river Krishna. The wall could not sustain the flood impact and there was a sliding, collapse and even rotational failure at some portion of wall was observed. Basically this wall was constructed to protect a village road about 1800m along a stream from flood water.

Failure of any structure is usually not attributable to a single cause but in the present case at the prima-facie, it seems that the wall failed due to heavy flood and backwater in the stream from river Krishna and the improper design criteria. The other principle causes of the failure are found out and the remedial measures have been suggested.

In this article, an attempt has been made by the authors to make an unbiased technological analysis of the data available, motivated by a desire to find ways of avoiding past mistakes and not sitting on judgment on them!

INTRODUCTION

Failure of any civil Engineering structure is usually not attributable to a single cause; likewise the presently stated retaining wall has not a single cause for its failure. Generally, it is the culmination of commutative errors committed at various stages such as (a) Collection of survey data, geotechnical investigation, assumptions of hydraulic parameters such as maximum mean velocity, discharge, maximum erosion of banks particularly for walls subjected to water front, Flood characteristics, maximum water level and discharge during flood etc. (b) Preparation of detailed retaining wall project and various assumption made while preparing the structural design such as safe bearing capacity, surcharge nature of back filling, soil thrust on wall, c-φ values, factor of safety to be allowed etc. (c) Faults committed during execution such as lack of past experience, the foundation strata of required bearing capacity, Earth pressure on wall, Selection of backfill material, etc. (d) Other environmental factors such as occurrence of unpredicted floods due to either heavy rainfall or together with opening of rates of major irrigation dam project on the u/s side.

In the present case the wall was designed as the R.C.C. Counterfort Retaining wall but the designer has not taken into account the considerations followed for the design of flood wall. The judgment was wrong and the whole structure collapsed. It was needed to design the wall as flood wall.

At this stage it is important to discuss the differentiating points between retaining wall and flood wall.

Differences between Retaining and Flood Walls

Purpose of Walls. A retaining wall is any wall that retains material to maintain a change in elevation whereas the principal function of a flood wall is to prevent flooding (inundation) of adjacent land. A floodwall is subject to water force on one side which is usually greater than any resisting earth force on the opposite side. A wall may be a retaining wall for one loading condition and a flood wall for another loading condition. The flood loading (surge tide, river flood, etc.) may be from the same or the opposite direction as the higher earth elevation.

Seepage and Leakage Control Requirements. All water-retaining structures may be subject to seepage through, under, and around them. Inadequate control of seepage may affect the stability of a flood wall regarding uplift or loss of support resulting from erosion. Properly controlled seepage, even if quantities of flow remain large, presents little or no hazard protection other than to relieve the hydrostatic load on the fill side of the wall. Water stops are used in retaining walls to prevent water passage from the backfill through the vertical joints.

BACKGROUND

There is a village Bamani @ 10 km from Sangli, a District place in southern part of Maharashtra in India. A village WBM road @ 13km in length connecting Bamani village to Dhamani, and village crosses a stream near Bamani. This road is along the length of the stream. The stream meets river Krishna one km ahead this village.

River Krishna is a major river passes through the southern part of Maharashtra. The back water of flooding of river enters in the stream and there is a danger of flood in village Bamani and Dhamani and also damage of the road which affects the transportation of people leaving in the village. Therefore there was a need of construction of a wall which protects the erosion of road from the backwater and flooding in the stream.

The bed slope to river Krishna is very less near Sangli as well to the stream too. Also there is black cotton soil present in the bed and all around the bank or the stream. There is continuous erosion and scoring of the bank and bed of the stream along the road takes place due to soft, loose silt clay all over the bank.

A counterfort R.C.C. retaining wall was constructed in the year 2002-03. The length of the wall is about 310 m no of counterforts at the backfill side. The height of the wall was 5 m above the foundation level. The superstructure of the wall was resting on pile foundation. The purpose of wall was to retain earth on one side for 5m height. The type of soil to be retained was B.C. soil. Also there is a road along the wall on the retained earth where two lane (multilane) traffic was expected. Coulomb's theory was used to calculate the earth pressure and for analysis and design of the wall.

DESIGN CONSIDERATIONS OF WALL

The wall was designed to retain earth on one side for 5m height. The soil to be retained is B.C. soil. The density of soil was considered as 1600 kg/m3 and angle of repose as 15. The face adjacent to earth to be retained was vertical. As the load was more, the provision of counterforts on soil side was made. The proportion of concrete was taken as 1:2:4. The back filling material choose was about 600 mm boulders.
IRC class AA loading and two lane (multi lane) traffic was expected on the soil behind the wall.

As black cotton soil is met within the foundation, it was proposed to provide 450 mm diameter RCC underream piles foundation for supporting the retaining wall. In that way the whole static load was considered to transfer to the pile foundation and accordingly pile group with supporting beams were designed.

There were two piles, one on toe side and other on heel side. Both together were expected to resist the overturning moment and sliding force. Necessary checks were furnished.

As retaining wall height above toe/heel base beam was 6m, to economies the counterforts for the vertical stem were provided. The stem was designed as a continuous slab for +ve B.M. of p12/16and –ve B.M. of p12/12 as per standard practice.

The effect of overturning moment was to induce compressive load on toe pile and tensile load on heel pile. The c/c distance between these piles was 2.75m.

Factor of safety against sliding was checked which was 1.892 and found to be safe. Counterforts were provided @ 3mc/c. Clear span of counterfort was 2.70m. The stem slab was continuous.

It was proposed to reduce the thickness of stem wall from 450mm@ base to 230mm @ top uniformly keeping soil face of wall as truly vertical. Check was therefore furnished @ 2m height / interval.

Counterfort took the soil pressure for 2.7m clear or 3mc/c span and was varying c/s i.e. 0 @ top to 1800 @ bottom. It was in triangular in shape. Depth of counterfort was 1724mm.

Heel slab was supported on pile. However the earth filling above heel slab put pressure on the counterfort and induce tensile stressed. Hence the provision of vertical stumps to counterforts was made.

Total vertical load was supported by piles and therefore wall base consisting of Toe slab and heal slab were designed as a pile cap/ beam in order to support the total load efficiently by piles.

The estimate of the wall was of Rs. 25 lakh.

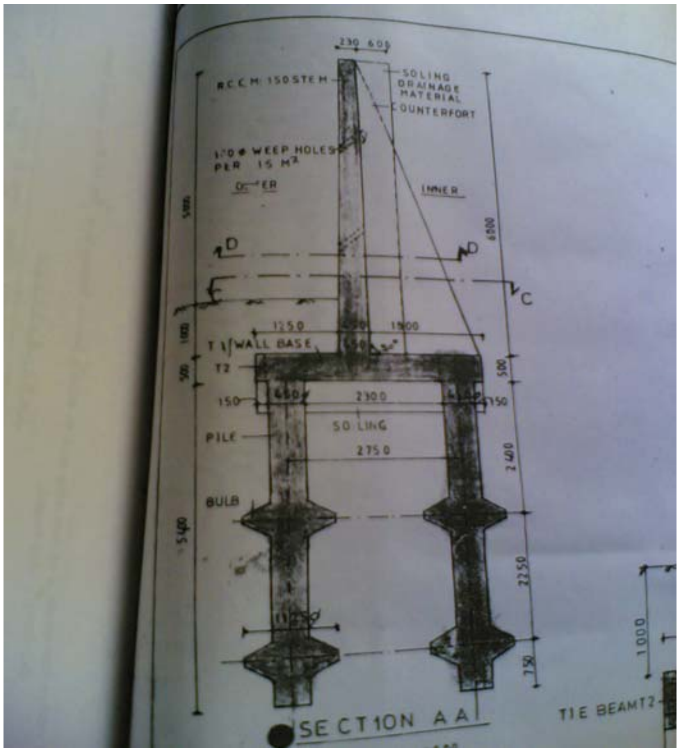

Figure 01

Above figure 01 shows the cross section of the wall which gives general idea about the wall with pile foundation

CAUSES OF FAILURE

Design Philosophy

Retaining walls are normally built as an appurtenance to other structures: dams, hydroelectric power houses, pump stations, etc. The consequences of failure of a retaining wall are often lower than for flood walls. Also, retaining walls are seldom more than a few hundred meters long; if they are designed conservatively, the added costs are of limited significance. Flood walls, on the other hand, are usually the primary feature of a local protection project. They must be designed for the most economical cross section per unit length of wall, because they often extend for great distances. Added to this need for an economical cross section is the requirement for safety. Thus, the design of retaining and flood walls is a complex process involving safety and economy factors, and design must be executed in a logical, conservative manner based on the function of the wall and the consequences of failure. Design documents should describe the decisions leading to the final degree of conservatism.

In the present case the wall was designed as a simple cantilever counterfort retaining wall. The wall would have designed as flood wall. If the wall would have designed as a flood wall, it would have not been collapsed. It is observed from the detailed design and analysis made of this wall that in whole design, no flood water forces (hydraulic forces) have been considered anywhere. Also the effect of pore water pressure was not predicted

Wall Stability

Generally, it is more difficult to design stable flood walls than retaining walls. By their very nature, flood walls are usually built in a flood plain which may have poor foundation conditions. Uplift is always a critical item with flood walls but seldom a problem with retaining walls since the loads acting on a retaining wall are usually soil backfills. The water load on a flood wall can be more severe, especially when wave loadings are applicable. When the ground-water surface is near or above the wall footing, a common occurrence with flood walls, the allowable bearing capacity of the soil is reduced. The reduction of stability, due to the erosion of the earth cover over and beyond the base, must be considered.

In the same manner here also the bearing capacity of the foundation soil is considerably reduced and the wall lost its stability due to the erosion of earth cover over and beyond the base due to heavy flooding continuously for two consequent years.

Engineering Team

A fully coordinated team of geotechnical and structural engineers, and hydraulic engineers where applicable, should ensure that all pertinent engineering considerations are properly integrated. Some of the critical aspects of design which require coordination are:

a. Preliminary estimates of geotechnical and hydraulic data, subsurface conditions, and types of structures which are suitable for the foundation.

b. Selection of design parameters, loading conditions, loading effects, potential failure mechanisms, and other related features of the analytical models.

c. Evaluation of the technical and economic feasibility of alternative types of structures.

d. Refinements of the preliminary structure configuration to reflect the results of detailed site explorations, material availability studies, laboratory testing, and numerical analysis.

f. Modification to the structure configuration during construction due to unexpected variations in the foundation conditions.

It is observed in the study of failure that, the geotechnical investigation was not made and the design parameters are considered on thumb rule basis. Also it was found that no geotechnical expert had appointed separately. Actually both geotechnical and structural aspects of wall design are included. Coordination between geotechnical engineers, structural engineers, and geologists in the design of retaining and floodwalls is essential.

Basically the selection of wall was not made proper. The wall would have selected as any type of flood wall (T-type or Ltype). The designer has not at all predicted such heavy rainfall and the flood in the stream and therefore the judgment went wrong.

It is also found that the studies of different alternative projects /schemes were not made which could have better feasibility.

Geotechnical Investigations

Planning the Investigation.

a. Purpose. The purpose of the geotechnical investigation for wall design is to identify the type and distribution of foundation materials, to identify sources and characteristics of backfill materials, and to determine material parameters for use in design analyses. Specifically, the information obtained will be used to select the foundation type and depth, design the foundation, estimate backfill pressures, locate the ground-water level, estimate settlements, and identify possible excavation problems. For flood walls, foundation under seepage conditions must also be assessed.

b. Review of Existing Information. The first step in an investigational program is to review existing data so that the program can be tailored to confirm and extend the existing knowledge of soil and rock conditions. In the case of flood walls, study of old topographic maps can provide information on past riverbank areas.

The wall failed because of improper design and construction errors. A large number of engineering errors and poor judgments" contributed to the design failures of the wall. No due considerations were given to the geotechnical investigation and the geological aspects of the site.

There was a lot of water pressure (Pore pressure) behind the wall during flooding was developed. This water pressure and velocity from the higher water level would have been sufficient to cause ground erosion in the river bank. With the erosion and saturation of the soil behind the wall which allowed the backfill material to move and remove support from the above material. This water found its way from under the footings, washing away the finer soil particles resulting in reduction of coefficient of friction.

The finer soil particles in the backfill were rendered into a semi-liquid condition increasing the active pressure. Thus the thrust at the back, helped by a large reduction in the frictional resistance, pushed out the wall bodily.

The type of the soil available at the site was the major problem. The failure mainly occurs due to the loose and silty soil. This soil would have treated to improve its bearing capacity.

Other Reasons

The hydrological data was not studied properly. Heavy rainfall and flood continuously for 2 years was not at all predicted.

Improper workmanship and inferior quality of work.

PHOTOGRAPHS OF FAILURE

Some of the photographs of the damaged wall are shown here to get the idea of the failure of the wall.

Photo 1

Photo 2

Photo 3

Photograph No.1,2 and 3 shows the total shifting of wall from its original position. The counterforts get exposed. The road along the stream is found to be completely damaged. The backfill material spread abruptly due to flood. The alignment of the wall is found to be changed completely. The entrance to the village Bamani is completely disturbed.

Photo 4

Photo 5

Photo 6

Photographs 4, 5 and 6 show the exposed reinforcement of the wall. The reinforcement is found to be completely damaged and lost the bond strength with concrete. Some patchwork is found in photograph 5.

Photo 7

Photograph 7 shows the honeycombing in concrete and the bad workmanship and quality of the work. The weep wholes are also seen in the photograph.

Photo 8

Photo 9

Photograph 8 and 9 shows a cross section and the longitudinal section of the damaged wall and some portion of the stream.

SUGGESTIONS

- The selection of wall should be made proper as per the fulfillment of the requirements.
- Both geotechnical and structural aspects of should be considered and included in wall design.
- The foundation for the wall should be checked for ensuring adequate factor of safety against or over turning and sliding for the condition of reduced vertical reaction.
- The HFL of the stream and the flood water pressure must be considered whenever these are a construction of flood / retaining wall. The wall must be designed for hydraulic consideration.
- Higher factor of safety against overturning and sliding should be ensured in case of flood walls.
- Back fill should be properly compacted and selection of backfill material should be made proper so that for flood water behind the wall would pass on the other side and the less pore water pressure will be develop.
- Careful attention must be given to wall monoliths that have loading, support, or other conditions that vary along the length of the monolith.
- There should be proper coordination between geotechnical engineers, structural engineers, and geologists in the design of retaining and flood walls.
- Evaluation of the technical and economic feasibility of alternative types of structures should be studied.
- The important civil engineering works should be should be completed by the experienced staff from the department as well as from the contractor side.
- Water stops should be used in retaining walls to prevent water passage from the backfill through the vertical joints.

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